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Instrumental and sensory quality characteristics of blueberry fruit from twelve cultivars

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Abstract

We compared the instrumental and sensory quality characteristics of blueberry fruit from ten highbush (*Vaccinium corymbosum* L.) cultivars, Chanticleer, Weymouth, Hannah's Choice, Duke, Bluecrop, Coville, Berkeley, Bluegold, Elliott and Lateblue and two rabbiteye (*Vaccinium virgatum* Aiton) cultivars, Coastal and Montgomery, grown in New Jersey. Cultivars varied in sensory intensity and acceptability scores. Highbush cultivars, Coville and Hannah's Choice, scored highest among the cultivars in sensory scores for intensity of blue color, juiciness, sweetness and blueberry-like flavor and for acceptability of appearance, color, fruit size, sweet/tart balance, flavor and overall eating quality. In contrast, rabbiteye cultivars, Coastal and Montgomery, and the highbush cultivars, Elliott and Weymouth, scored lowest among the cultivars in sensory scores for intensity of bursting energy, skin toughness, texture during chewing, juiciness, and blueberry-like flavor and for acceptability of appearance, color, fruit size, flavor and overall eating quality. Analytical quality characteristics of surface color, size, compression firmness, soluble solids content (SSC), pH, titratable acidity (TA), SSC/TA ratio, and aromatic volatile concentration also varied among cultivars, but no instrumental measurement adequately predicted consumer acceptability scores. The overall eating quality of blueberry fruit was best correlated with flavor scores followed by sensory scores for intensity of juiciness, bursting energy and sweetness and for acceptability of appearance.
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Keywords: *Vaccinium corymbosum*; *Vaccinium virgatum*; Cultivars; Aromatic volatiles; Firmness; Fruit size; Surface color; Soluble solids content; Titratable acidity

1. Introduction

Blueberries are one of the few fruit crops that are native to North America and, next to strawberries, are the second most important berry in the U.S. The market for cultivated blueberries has more than tripled since the 1970s and, since 2000, has increased at a rate of 10–20% annually, influenced, in large part, by Americans' increased desire for a healthy and nutritious diet (USDA Economic Research Service, 2003; USDA National Agricultural Statistics Service, 2006). Utilized yield of the U.S. grown cultivated blueberries was >125 million kg in 2006. Of this amount, 38 and 24 million kg with respective values of US$ ~140 and ~84 million were produced in Michigan and New Jersey, respectively (USDA National Agricultural Statistics Service, 2006). While both highbush and rabbiteye blueberries are cultivated commercially in the U.S., ~95% of cultivated blueberries consists of highbush cultivars, which thrive in northern temperate zone climates.

Since fresh blueberries are not typically sold as a varietal fruit, high fruit yield and firmness to withstand shipment to distant markets have always been important selection criteria. 'Bluecrop', released in 1952, has firm fruit and dependably high yields and is now the most widely planted blueberry cultivar (Hancock, 2001). With an increased consumption of fresh blueberries in the past two decades, a whole new generation of cultivars has been released that were bred, at least in part, for improved fruit quality, shelf stability and extension of the fresh-market harvest season. 'Duke' is a clear leader in this group, widely planted for its earliness and its large firm fruit (Hancock, 2001). Fruit of other cultivars in this group are noted for their earlier ripening (e.g., 'Chanticleer'), better shelf stability (e.g., 'Bluegold') or improved instrumental quality (e.g., 'Hannah's Choice') when

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compared to fruit of 'Bluecrop' and other widely planted, high yielding cultivars (Hancock, 2001; Adelaja and Knipling, 2000).

While many research papers have been published on instrumental quality characteristics of highbush and rabbiteye blueberries (Silva et al., 2005), very little information is available regarding their sensory characteristics. Sensory evaluations of thawed highbush and rabbiteye blueberries showed that 17 panelists preferred the color of rabbiteye to highbush blueberries, but thawed fruit of highbush cultivars had superior taste and texture and less seediness (Makus and Morris, 1993). More recent sensory evaluations of fresh highbush and rabbiteye blueberries showed that 10 trained panelists found no differences in fruit color, flavor or skin toughness among three rabbiteye and two highbush cultivars (Silva et al., 2005). Another trained panel of nine members found that temperature and packaging film type affected sensory scores for texture and blueberry flavor of stored fruit from the highbush cultivar, Bluecrop (Rosenfeld et al., 1999). Various postharvest treatments are being tested to maintain and/or enhance sensory quality of stored blueberries (Nunes et al., 2004; Paz et al., 1982; Trigo et al., 2006). However, there have been no comprehensive evaluations of blueberry cultivars for eating quality, nor has there been any attempt to correlate those findings with instrumental measurements.

1.1. Objectives

- To determine consumer preferences of fresh-market highbush and rabbiteye blueberries from cultivars grown in New Jersey.
- To identify sensory and instrumental quality characteristics that may predict consumer acceptability of blueberry eating quality.

2. Materials and methods

2.1. Plant material

Highbush blueberries (*Vaccinium corymbosum*) were hand harvested from mature field-grown plants at the P.E. Marucci Center for Blueberry and Cranberry Research, Chatsworth, NJ, on June 26 (cvs. Chanticleer, Duke, Hannah's Choice and Weymouth), July 10 (cvs. Berkeley, Bluecrop, Bluegold, and Coville) and July 24 (cvs. Elliott and Lateblue) of 2006. During the last harvest, rabbiteye blueberries (*Vaccinium virgatum*, cvs. Coastal and Montgomery) were also picked. For each cultivar, only mature, fully colored unblemished fruit that felt firm to the touch were picked from three plants (replicates) and the fruit from each plant were separately packed in vented, lidded containers and stored in air at 5 °C for 1 or 2 d prior to instrumental analyses (with the exception of aromatic volatile analyses, see below). Replicate samples from each cultivar and each harvest were shipped overnight in foam coolers with cold-packs to the ARS Beltsville Agricultural Research Center, Beltsville, MD, where the fruit were sorted to remove any transit-damaged fruit. The rest were stored in air at 5 °C for 1 or 2 d before aromatic volatile and sensory quality analyses.

2.2. Sensory analyses

At 2 and 3 d after each harvest in 2006, we evaluated the eating quality of four cultivars. Beltsville Agricultural Research Center staff volunteers who like blueberries, eat them frequently, and had no knowledge of the experiments (60 consumers per experiment, 10 panelists per session, with some repeat panelists among experiments) evaluated a 4–7-fruit sample (~12 g) from a commercial lot of blueberries (purchased from a local supermarket, cultivars unknown) and the four cultivars from each harvest date. Preliminary tests had indicated that ~12 g of fruit was sufficient for rating sensory quality characteristics despite fruit-to-fruit variations in quality. At the time of consumer evaluation, fruit were equilibrated to 23 °C for 2 h. The commercial sample was presented first as a warm-up to satisfy the "placebo effect" and to familiarize panelists with the evaluation procedure followed by the four cultivars in random order. The same order was used for 10 panelists within a panel session, respective to the four possible ordered sequences of cultivars. For each experiment/harvest, six panel sessions were performed, two sessions for each replicate of each cultivar. Each panelist evaluated all five samples with the four cultivars serving as a complete block in the statistical design. Samples were presented one at a time in individual booths under moderate incandescent lighting. Panelists were required to cleanse their palates with a bite of low-salt saltine cracker, a sip of room temperature water and a small time lag before every sample. On unstructured scales labeled on both ends, panelists rated the intensity of blue color (scales labeled *light* to *dark*), bursting energy (*mushy* to *rigid*), skin toughness (*tender* to *tough*), texture during chewing (*soft* to *firm*), juiciness (*not juicy* to *very juicy*), sweetness (*not sweet* to *very sweet*), tartness (*not sour* to *very sour*) and blueberry-like flavor (*not blueberry* to *very blueberry*) and the acceptability of appearance, color, fruit size, sweet/tart balance, flavor and overall eating quality (scales for acceptability characteristics each labeled *unacceptable* to *excellent*). Blueberry descriptors were chosen based on prior solicited comments from scientists familiar with fresh-market blueberry quality characteristics. Comments from panelists were solicited on the ballots. Panelists were asked to indicate gender and age in decades. On-screen ballots were prepared and data was collected using Compusense Five (Version 4.2; Compusense Inc., Guelph, Ontario, Canada).

2.3. Instrumental analyses

Surface color (CIE $L^* a^* b^*$), individual fruit weights, fruit weight and count in a 236.6-mL cup, compression firmness, soluble solids content (SSC), titratable acidity (TA), SSC/TA ratio, pH and aromatic volatile concentration were measured on intact blueberries or extracts thereof at 2–3 d after each harvest, i.e., at the time of each sensory quality experiment. For each replication of each cultivar, the surface color of blueberries was measured using a Minolta Chroma Meter (model CR-210, Osaka, Japan) calibrated with a white tile. For relative fruit size, the weight of 15 fruit was individually measured and the combined weight and cup count (the number of fruit fitting in a standard U.S.

liquid measure 236.6 mL (8 oz) cup with not more than half of any fruit above the rim) were also determined. For compression firmness, an individual fruit (50 total) was positioned on its side and compressed equatorially in 0.05 mm steps, measuring the mm of deflection between the minimum (0.15 N) and maximum (1.96 N) force thresholds using a FirmTech 2 firmness tester (BioWorks, Stillwater, OK). Firmness results are reported as the mean force (N) to deflect the surface of the fruit 1 mm.

Soluble solids content, pH, TA and aromatic volatile concentration were determined using freshly prepared juice. For each replication of each cultivar, a 250 mL beaker was filled to the 150 mL mark with whole fruit, the fruit were pureed using a hand-held blender and the resulting pulp was strained through two layers of cheesecloth. The SSC was measured using a digital refractometer (model PR-101, Atago, Co., Tokyo, Japan); TA (expressed as citric acid) was measured by titrating two 100-mL samples of 5% extracted juice with 0.1 mol L^{-1} NaOH to pH 8.1.

Analysis of aromatic volatile concentration using a solid-phase microextraction (SPME, Supelco Co., Bellefonte, PA, USA) technique and gas chromatography-flame ionization detector (GC-FID) (model 6890, Agilent Technologies, Rockville, MD, USA) was performed as described in Saftner (1999) except that the SPME used for volatile collection was coated with 75 μm carboxen-polydimethylsiloxane. Constructing calibration curves for each analyte in each blueberry juice sample is not feasible and thus total volatile concentration is reported in detector area response units of picoamps (pA) rather than absolute amounts (Saftner et al., 2002).

2.4. Statistical analysis

Data were analyzed using PROC MIXED (SAS Version 9.13, SAS Institute, Inc., Cary, NC). Data from the three experiments were combined, and the experimental design was a randomized complete block with three replications. Sources of variation were cultivars (12) and replications (3), both considered fixed effects, and panel sessions (6) and panelists (60), considered random effects. Relationships of cultivar preference relative to gender and age were examined using analysis of covariance (ANCOVA) (Littell et al., 1996). Treatment differences were tested using Tukey–Kramer tests, $\alpha = 0.05$. For sensory–sensory and instrument–sensory comparisons, raw data was used to calculate Pearson correlation coefficients which were used to model the relationships (SAS Version 9.13, SAS Institute, Inc.): (*), (**), and (***) are used in the text to indicate 0.05, 0.01 and 0.001 levels of significance, respectively. Sensory data were additionally examined by Factor Analysis (FA) using the Promax (Oblique) Rotation Method via SAS Proc FACTOR to extract four factors. The FA "re-partitions" the sensory–sensory correlation matrix to extract factors that describe variability shared in common among the sensory descriptors. The oblique rotation method allows the variability represented by these extracted factors to be correlated with one another, just as many of the sensory descriptors are correlated with one another. Unless stated otherwise, only results significant at $P \le 0.05$ are discussed.

3. Results and discussion

3.1. Sensory quality

For fruit of all cultivars evaluated, sensory scores for intensity and acceptability of visual quality characteristics were good (scores of 40–70) to excellent (scores > 70) (Table 1). Among textural quality characteristics, scores were generally good for intensity of juiciness and acceptability of texture during chewing (not measured in early season cvs.), with relatively low scores (<40) for skin toughness. All fruit, with the exception of 'Coville', had relatively low scores for intensity of bursting energy (i.e., crispness) and texture during chewing (Table 2). Flavor-related and overall eating quality scores were generally in the good range (Table 3). Solicited comments of the panelists were >80% favorable, with sensory quality characteristics being described with such words as *nice*, *good*, *excellent*, *like*, *perfect* and *great*. Since comments were generally favorable and since scores for overall eating quality were all ~40 or higher, fruit of all cultivars were considered to be of at least acceptable eating quality.

Among cultivars, fruit varied in all sensory quality scores. 'Coville' and 'Hannah's Choice' scored highest in overall eating quality though not significantly different than five other highbush cultivars (Table 3). Both 'Hannah's Choice' and 'Coville' scored high for intensity of sweetness and blueberry-like flavor and for acceptability of sweet/tart balance and flavor. 'Hannah's Choice' scored higher than 'Coville' in all visual quality characteristics whereas 'Coville' scored higher than 'Hannah's Choice' (and many other cultivars) in all textural quality characteristics, except juiciness, where both scored the same (Table 2). While not always significant, the numerical differences in sensory quality characteristics between 'Hannah's Choice' and 'Coville' were sometimes large and likely to be of practical importance. Except for intensity of bursting energy and texture during chewing, 'Chanticleer' had sensory quality characteristics similar to those of 'Hannah's Choice' and 'Coville'. The differences in overall eating quality between 'Chanticleer' and 'Hannah's Choice' or 'Coville' are probably not great enough to be of any practical importance.

In contrast, the rabbiteye cultivars, Coastal and Montgomery, and the highbush cultivars, Elliott and Weymouth, scored low in sensory scores for intensity of bursting energy, skin toughness, texture during eating, juiciness (Table 2), blueberry-like flavor (Table 3), and for acceptability of appearance, color, fruit size (Table 1), flavor and overall eating quality (Table 3). The two rabbiteye cultivars scored lowest among cultivars for acceptability of color and fruit size (Table 1). 'Weymouth' scored lowest for intensity of juiciness and texture during chewing (Table 2) and 'Elliott' scored lowest for intensity of sweetness and blueberry-like flavor and for acceptability of sweet/tart balance, flavor and had the highest sensory score for intensity of tartness (Table 3). A few panelists commented that fruit of the rabbiteye cultivars were *too small*, 'Weymouth' was *too soft* and 'Elliott' was *tart*. These results suggest that the rabbiteye cultivars had a lower visual quality, 'Weymouth' a lower textural quality and 'Elliott' a lower taste quality compared to the

Table 1
Sensory panel scores of visual quality characteristics for blueberry fruit from 12 cultivars ranked by ripening season

Cultivar	Visual quality characteristics[a]			
	Appearance acceptability	Blue-color intensity	Color acceptability	Fruit size acceptability
Chanticleer	73.5 a–e	75.9 a-c	81.8 a–c	79.4 a–c
Duke	81.7 ab	74.8 a–d	85.1 ab	82.3 ab
Hannah's Choice	83.4 a	77.6 ab	87.5 a	83.4 a
Weymouth	69.7 de	78.9 ab	82.5 a–c	68.4 d
Berkeley	80.9 ab	63.8 d	76.0 b–d	83.4 a
Bluecrop	73.7 a–e	68.2 b–d	76.5 b–d	77.7 a–d
Bluegold	71.2 b–e	64.0 d	74.0 cd	76.3 a–d
Coville	75.9 a–d	70.3 a–d	77.6 b–d	79.3 a–c
Elliott	75.8 a–d	69.4 a–d	77.3 b–d	81.8 ab
Lateblue	80.6 a–c	80.6 a	82.3 a–c	85.1 a
Coastal	63.5 e	78.3 ab	69.8 d	72.0 b–d
Montgomery	69.8 c–e	65.7 cd	71.8 d	71.1 cd

[a] Means within a column followed by the same letter (a–e) were not significantly different, Tukey's HSD ($\alpha = 0.05$, $n = 60$).

Table 2
Sensory panel scores of textural quality characteristics for blueberry fruit from 12 cultivars ranked by ripening season

Cultivar	Textural quality characteristics[a]				
	Bursting energy intensity	Skin toughness intensity	Texture during chewing		Juiciness intensity
			Intensity	Acceptability	
Chanticleer	28.7 c–e	29.5 b–d	22.9 cd	nd[b]	54.1 a
Duke	46.6 ab	38.3 ab	38.8 ab	nd	49.2 ab
Hannah's Choice	40.8 bc	27.5 b–d	30.6 b–d	nd	56.8 a
Weymouth	26.0 de	26.6 cd	20.6d	nd	40.2 b
Berkeley	41.1 bc	36.4 a–d	37.6 ab	58.4 ab	54.4 a
Bluecrop	38.3 b–d	25.9 d	30.4 b–d	55.0 ab	50.4 ab
Bluegold	35.2 b–e	32.2 a–d	29.0 b–d	46.8 bc	44.7 ab
Coville	53.8 a	37.0 a–d	46.4 a	67.9 a	56.0 a
Elliott	41.0 bc	38.1 a–c	35.6 ab	49.5 b	48.9 ab
Lateblue	37.9 b–d	28.3 b–d	33.2 bc	54.0 b	56.4 a
Coastal	23.8 e	30.8 b–d	21.6 cd	34.9 c	52.2 ab
Montgomery	38.8 bc	43.1 a	33.6 bc	49.3 b	50.7 ab

[a] Means within a column followed by the same letter (a–e) were not significantly different, Tukey's HSD ($\alpha = 0.05$, $n = 60$).
[b] nd: Not done.

Table 3
Sensory scores for flavor-related and overall eating quality characteristics for blueberry fruit from 12 cultivars ranked by ripening season

Cultivar	Flavor-related and eating quality characteristics[a]					
	Sweetness intensity	Tartness intensity	Sweet/tart balance	Blueberry flavor intensity	Flavor acceptability	Overall eating quality
Chanticleer	55.3 ab	42.9 de	59.0 ab	61.5 a	63.4 a	59.6 a
Duke	51.0 a–c	40.1 de	55.6 a–c	51.7 ab	54.8 a–c	56.8 a–c
Hannah's Choice	58.3 a	38.9 e	61.8 a	63.1 a	66.1 a	66.5 a
Weymouth	53.4 a–c	41.6 de	50.9 a–d	53.6 ab	52.1 a–c	49.3 b–d
Berkeley	53.6 a–c	41.6 de	55.7 a–c	54.7 ab	57.8 ab	58.9 ab
Bluecrop	51.1 a–c	47.2 c–e	56.0 a–c	56.3 ab	57.0 ab	56.4 a–c
Bluegold	43.8 b–d	58.5 a–c	50.6 a–d	50.7 ab	52.4 a–c	49.2 b–d
Coville	48.9 a–c	52.9 b–d	62.8 a	61.3 a	65.5 a	67.2 a
Elliott	33.5 d	70.6 a	39.9 d	43.5 b	42.0 c	42.0 cd
Lateblue	42.5 bc	65.6 ab	51.7 a–d	57.3 ab	57.6 ab	57.6 ab
Coastal	52.2 a–c	24.6 f	43.9 cd	45.8 b	46.0 bc	39.2 d
Montgomery	41.5 cd	51.6 c–e	45.4 b–d	49.9 ab	47.8 bc	47.2 b–d

[a] Means within a column followed by the same letter (a–e) were not significantly different, Tukey's HSD ($\alpha = 0.05$, $n = 60$).

other cultivars. The results are also consistent with previous reports that rabbiteye cultivars generally have smaller fruit than highbush cultivars (Makus and Morris, 1993), 'Weymouth' has relatively soft fruit (Ehlenfeldt and Martin, 2002) and 'Elliott' fruit are high in acid (Sapers et al., 1984). The numerical difference in sensory quality characteristics between the higher and lower scored cultivars was large in most cases and clearly indicated a real preference.

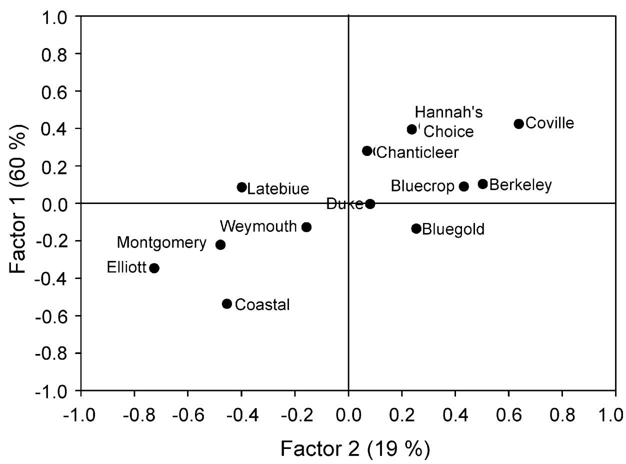

Fig. 1. Factor Analysis of sensory data for all 12 blueberry cultivars.

Factor Analysis was conducted on the sensory data to identify variability shared in common among the sensory descriptors (i.e., factors) for the 12 cultivars examined. The Promax Rotation Method was applied to the extracted factors to identify and estimate any correlation among the extracted factors. Cultivars Coville, Hannah's Choice and Chanticleer that had generally high scores for flavor and textural quality characteristics also had positive scores for Factor 1 (explaining 60% of the variation observed among the sensory descriptors), with high loading values for blueberry flavor, sweetness, tartness, sweet/tart balance, juiciness and texture during chewing (Fig. 1). Likewise, cultivars that had generally low scores for flavor and textural quality had negative scores on Factor 1, and cultivars that had generally intermediate flavor and textural quality characteristics had scores near zero for Factor 1. Factor 2 explained 19% of the variation observed among the sensory descriptors and acceptability of color, flavor and overall eating quality loaded onto this factor. Cultivars that scored generally high for color, flavor and overall eating quality had positive scores for Factor 2 and cultivars that scored lowest in these sensory quality characteristics had negative scores for Factor 2. Just as the sensory descriptors loading onto Factor 1 and 2 are correlated with one another, the oblique rotation of the factors estimates a correlation between Factor 1 and 2 of 0.42. In summary, Factor Analysis indicated that cultivars Coville, Hannah's Choice, Chanticleer, Berkeley and Bluecrop had higher sensory quality than cultivars Coastal, Elliott, Montgomery and Weymouth with 'Coville' having the best and 'Coastal' and 'Elliott' having the lowest, albeit still acceptable, sensory quality. Results from Factor Analysis were similar to other statistical analyses of the sensory data as described above.

We speculated that gender and age might influence consumer preferences, so these were included on the ballots. No age bias was shown for any of the sensory quality characteristics, but there was some gender bias, with females scoring visual quality characteristics for acceptability of appearance, color and fruit size higher than males (data not shown).

We also considered the possibility that maturity (i.e., ripeness) differences among cultivars may have affected the sensory results. Care was taken to harvest fruit once the fruit turned fully blue and was firm to touch, but slight differences in maturity among cultivars probably occurred. For example, the rabbiteye cultivar, Coastal, scored low for intensity of texture during chewing despite the fact that fruit of rabbiteye cultivars are generally firmer than those of highbush cultivars (Silva et al., 2005). Since firmness varies dramatically with the stage of maturity (Ballinger et al., 1973), the relatively low textural quality scores of 'Coastal' combined with its high sweetness and low tartness scores, which are characteristic of more mature fruit (Galletta et al., 1971), may indicate that these fruit were harvested at a somewhat more advanced stage of maturity than those of other cultivars to which they are being compared. While 'Coastal' is soft, sweet and good flavored compared to many older rabbiteye cultivars (Ehlenfeldt, personal observation), textural and flavor-related sensory scores of 'Coastal' should still be interpreted with caution.

When blueberries are grown in a single location and year, genetic factors are more important than environmental differences within the field (Ballington et al., 1984). Thus, this study reflects, by design, primarily genetic differences. Effects of environmental factors on blueberry fruit quality were not considered in this study, but should be minimal, at least within a harvest.

3.2. Sensory relationships

A long-term goal of our research is to better understand the relationships among sensory quality characteristics of blueberries, with the purpose of more accurately assessing the impact of sensory quality characteristics on eating quality. For the 12 cultivars used in this study, overall eating quality was most highly correlated with flavor acceptability ($r=0.87^{***}$) and blueberry-like flavor intensity ($r=0.85^{***}$). Eating quality was also correlated with sensory textural scores for juiciness ($r=0.68^{***}$), bursting energy ($r=0.53^{***}$), texture during chewing ($r=0.44^{**}$), and scores for acceptability of appearance ($r=0.57^{***}$), color ($r=0.45^{**}$) and size ($r=0.42^{**}$). Overall eating quality was also weakly correlated with sweetness intensity ($r=0.44^{**}$) and sweet/tart balance acceptability ($r=0.33^{*}$). Sweetness intensity was correlated to flavor intensity ($r=0.63^{***}$) and flavor acceptability ($r=0.70^{***}$). These results suggest that flavor-related characteristics best predict consumer preferences for overall eating quality, though textural and visual quality characteristics also contribute.

Sensory scores for appearance were best correlated with acceptability of fruit size ($r=0.85^{***}$) followed by acceptability of color ($r=0.68^{***}$). Within the ranges of fruit size and color evaluated, these results suggest that fruit size is a better indicator of sensory visual quality than the acceptability and intensity of fruit color (e.g., blue chroma).

3.3. Instrumental quality

Surface color ($L^*a^*b^*$), individual fruit weight, fruit count and weight in a standard 236.6-mL cup (Table 4), compression firmness, SSC, TA, SSC/TA ratio, juice pH, and aromatic volatile concentration (Table 5) varied among cultivars. 'Coastal', 'Weymouth' and 'Chanticleer' had lower L^* values (i.e., were darker),

Table 4
Surface color, individual fruit weight and fruit weight and count in a 236.6-mL cup of blueberry fruit from 12 cultivars ranked by ripening season

Cultivar	Surface color[a]			Individual fruit weight (g)	Standard 236.6-mL cup	
	L^*	a^*	b^*		Fruit count	Fruit weight (g)
Chanticleer	24.52 c–e	−0.09 a–c	−4.90 bc	2.09 c–e	74.5 a–c	156.2 b–d
Duke	27.21 a–c	−0.13 a–c	−5.36 bc	2.38 bc	62.7 cd	150.7 d
Hannah's Choice	26.28 a–d	−0.03 ab	−5.11 bc	2.85 a	57.3 d	156.1 b–d
Weymouth	21.94 de	−0.04 ab	−3.94 ab	1.56 f	nd	nd
Berkeley	30.84 ab	−0.70 bc	−5.10 bc	2.48 a–c	67.0 b–d	163.0 ab
Bluecrop	27.33 a–c	0.09 a	−5.48 bc	2.41 bc	68.0 b–d	166.2 a
Bluegold	30.12 ab	−0.66 bc	−5.70 c	2.57 ab	59.0 d	157.0 b–d
Coville	27.51 a–c	−0.01 ab	−5.30 bc	2.24 b–d	72.7 a–c	161.8 a–c
Elliott	31.73 a	−0.78 c	−4.79 bc	1.94 de	79.3 ab	151.4 d
Lateblue	26.16 a–d	−0.32 a–c	−3.88 ab	2.45 bc	70.3 b–d	150.2 d
Coastal	20.29 e	0.11 a	−2.39 a	1.84 ef	85.0 a	150.4 d
Montgomery	27.73 a–c	−0.37 a–c	−2.30 a	1.66 f	101.0	154.6

[a] Means within a column followed by the same letter (a–f) were not significantly different, Tukey's HSD ($\alpha = 0.05$, $n = 9$ for surface color values, $n = 10$ for individual fruit weight, and $n = 3$ for fruit count and weight in a cup except for 'Montgomery' where $n = 1$).

Table 5
Compression firmness of whole blueberries and SSC, TA, pH, and aromatic volatile concentration of blueberry extracts from 12 cultivars ranked by ripening season

Cultivar	Compression firmness (N)[a]	SSC (%)	TA (%)	SSC/TA ratio	pH	Aromatic volatile concentration (pA)
Chanticleer	1.56 b–d	13.0 a	0.40 bc	32.3 ab	3.4 a	1397 g
Duke	1.67 a–c	10.9 b–d	0.43 bc	25.5 b–d	3.0 a–c	2739 a–c
Hannah's Choice	1.86 a	12.3 ab	0.45 bc	27.3 a–c	3.3 ab	1768 fg
Weymouth	1.51 cd	11.2 b–d	0.56 bc	20.1 cd	2.8 bc	3375 a
Berkeley	1.54 cd	11.5 b–d	0.44 bc	26.6 b–d	3.1 ab	3035 ab
Bluecrop	1.64 a–c	11.5 b–d	0.46 bc	24.9 b–d	3.1 ab	2243 c–f
Bluegold	1.71 a–c	13.2 a	0.64 b	20.9 cd	3.1 a–c	2555 b–d
Coville	1.66 a–c	10.8 cd	0.58 bc	18.7 d	3.0 a–c	2450 b–e
Elliott	1.64 a–c	11.3 b–d	1.27 a	9.0 e	2.5 c	1994 d–g
Lateblue	1.40 d	10.6 d	1.22 a	8.9 e	2.5 c	1820 e–g
Coastal	1.37 d	12.2 a–c	0.35 c	35.6 a	3.0 a–c	2432 b–e
Montgomery	1.76 ab	11.3 b–d	0.58 bc	19.5 cd	2.8 bc	1764 fg

[a] Means within a column followed by the same letter (a–g) were not significantly different, Tukey's HSD ($\alpha = 0.05$, $n = 3$).

than the other cultivars, 'Bluegold' had the most blue chroma (i.e., most negative b^*) and 'Montgomery' the least (Table 4). Variations in green (negative a^*) and red (positive a^*) chromas among cultivars was not as large as that for blue chroma. Cultivars with darker colored fruit also had high sensory scores for intensity of blue color suggesting that the numerical difference in surface lightness (L^*) among cultivars was large enough to affect visual perception. It is likely that surface bloom (wax) affected the L^* value (i.e., higher amounts of surface bloom might lighten the fruit), as well as visual perception of fruit color (e.g., blue chroma). However, surface bloom (wax) was not specifically evaluated in this study. Cultivars with high sensory scores for intensity of blue color tended to have more negative b^* chromaticity values, i.e., had more blue chroma.

'Weymouth', 'Montgomery' and 'Coastal' had the lowest individual fruit weights, being 35–45% lower than 'Hannah's Choice', the cultivar with the highest fruit weight (Table 4). The difference in fruit size among cultivars was significant and of practical importance with larger fruited cultivars being preferred to smaller fruited ones. The small-fruited cultivars also scored lowest for acceptability of fruit size and overall eating quality.

'Coastal', 'Lateblue', 'Weymouth' and 'Chanticleer' were softer than other cultivars and were between 16 and 24% softer than 'Hannah's Choice', the cultivar with the firmest fruit (Table 5). Cultivars with lower compression firmness had low sensory scores for bursting energy and texture during chewing.

Soluble solids content differed by as much as 2.6% among cultivars with 'Bluegold' and 'Lateblue' having the highest and lowest SSC, respectively (Table 5). However, cultivars with high and low SSC did not match cultivars with high and low sensory scores for intensity of sweetness (Tables 3 and 5), which may indicate that the difference in SSC among cultivars may not be large enough to have any practical importance regarding perception of fruit sweetness. Alternatively, perception of sweetness may have been affected by other factors, such as TA. The difference in TA among cultivars was large. TA was 2–4 times higher in 'Elliott' and 'Lateblue' compared to the other cultivars (Table 5). Correspondingly, these two cultivars had the lowest juice pH. 'Elliott' and 'Lateblue' also had the highest sensory scores for tartness and among the lowest for acceptability of sweet/tart balance (Table 3). These results indicate the difference in TA among cultivars was large enough to impact sensory perception. There were also large differences in the SSC/TA ratio among cultivars, due mostly to the numerical difference in TA, with 'Elliott' and 'Lateblue' having the lowest ratio values (Table 5). Beaudry (1992) has suggested that blueberries should contain >10% SSC, 0.3–1.3% TA, a pH between 2.25 and 4.25 and a SSC/TA ratio between 10 and 33. Based on these quality standards, all cultivars evaluated in this study were of acceptable SSC, TA and pH but 'Coastal', 'Elliott' and 'Lateblue' were slightly out of the acceptable range for SSC/TA ratio (Table 5).

The difference in the aromatic volatile concentration among cultivars was large with 'Weymouth' containing more than twice the concentration of volatiles than 'Chanticleer' (Table 5). Despite the large difference in aromatic volatile concentrations, the impact on sensory flavor-related quality characteristics was not clear.

3.4. Instrument–sensory relationships

An underlying goal of our long-term research is to better understand the relationships of instrumental measurements to sensory assessments of fruits and vegetables, with the purpose of improving how we collect and interpret instrumental quality measurements. It is often desirable to have instrumental measurements of quality because it is generally not feasible to have consumers or trained panelists evaluate fruit and vegetables in breeding programs, physiological research or during commercial production. To that end, we compared color and size, chemical and compression firmness measurements to consumers' scores for visual, flavor and textural quality characteristics, respectively, to determine how well the instruments could predict the sensory scores.

Blueberry color is a complex quality characteristic affected by anthocyanin content (Kushman and Ballinger, 1975) and the quantity and structure of surface waxes (Albrigo and Hall, 1980). However, routine assessment of anthocyanin content and surface waxes is not practical. As an alternative, color measurements were used to measure the overall 'blueness' of the fruit. Surface L^* values were negatively correlated with sensory scores for intensity of blue color ($r = -0.62^{***}$) and significantly, albeit rather weakly, correlated with sensory scores for acceptability of appearance ($r = 0.46^{**}$). Chromaticity b^* values were correlated with sensory scores for intensity of blue color ($r = 0.48^{**}$) and were negatively correlated to sensory scores for acceptability of appearance ($r = -0.41^{*}$). These results might indicate that consumers' preferences are for brighter, less intensely blue-colored fruit.

Compression firmness values were best correlated with sensory scores for juiciness ($r = 0.48^{**}$) followed by bursting energy (crispness, $r = 0.44^{**}$) and texture during chewing ($r = 0.33^{*}$), and were not associated with sensory scores for intensity of skin toughness. The rather weak correlation between compression firmness and sensory scores for texture during chewing may be due to the abundance and/or size of stone cells and seeds which are likely to affect consumer textural scores more than instrumental compression values. Alternatively, blueberry firmness is more affected by changes in maturity than by differences among cultivars (Beaudry, 1992) and slight maturity differences among cultivars may have reduced the relationship between instrumental firmness and sensory textural scores.

Soluble solids content values were not correlated with sensory scores for intensity of sweetness or to any other sensory quality characteristic. Kader et al. (2003) has shown that anthocyanins strongly refract light and contribute to SSC values in samples containing these pigments. Thus, SSC is probably not as good an indicator of sugar concentrations in fruit extracts of blueberry as it is in other less-pigmented fruit extracts. Further research is needed to determine how well SSC relates to sugar concentrations in blueberries and the degree to which sugars affect sensory scores for sweetness, flavor and overall eating quality in this fruit. The pH values of blueberry extracts were correlated with scores for intensity of flavor ($r = 0.56^{***}$) and for acceptability of flavor ($r = 0.51^{**}$) and overall eating quality ($r = 0.48^{**}$). TA was inversely correlated with pH ($r = -0.76^{***}$) as expected, but it was not related to scores for tartness or to any other flavor-related quality characteristic. Similarly, Rosenfeld et al. (1999) reported that pH and TA were inversely correlated in 'Bluecrop' blueberry fruit and that TA values were not correlated with trained-panelists scores for intensity of acid taste [tartness] or blueberry-like flavor. The apparent lack of correlation between TA and flavor-related scores may indicate that there is an optimal acid concentration needed in blueberry fruit for enhanced flavor. In addition, other chemical factors such as sugar concentrations may be interacting with acid concentrations to affect tartness, sweetness and other flavor quality characteristics. A 0.1% decrease in acid concentration is known to be equivalent to a 1% increase in perceived sweetness in blueberry fruit (Beaudry, 1992). Alternatively, specific sugar and acid combinations may be needed to accentuate sensory scores for intensity of tartness, sweetness and blueberry taste.

Individual fruit weight values were correlated with scores for acceptability of size ($r = 0.67^{***}$), appearance ($r = 0.62^{***}$) and overall eating quality ($r = 0.47^{**}$). Individual fruit weight was negatively correlated with cup count ($r = -0.88^{***}$) as expected, and cup count was inversely correlated with scores for acceptability of fruit size ($r = -0.53^{**}$), appearance ($r = -0.54^{**}$) and overall eating quality ($r = -0.40^{*}$). These results indicate that smaller blueberries were generally less well liked than larger ones and that individual fruit weights were a better measure of sensory quality than cup count, though both provided a reasonable estimate of the visual acceptance of blueberries.

Total aromatic volatile concentrations, collected and concentrated from fruit extracts using a SPME technique, were not correlated with sensory scores for flavor, overall eating quality or to any other sensory characteristic. Thus volatile concentration, at least when analyzed using a SPME technique, is not a good indicator of blueberry taste or overall eating quality.

While there were many significant sensory–instrumental relationships, none of the predictions of sensory scores from instrumental measurements is high enough to have any practical use. That is not to say that *intensity* of these sensory quality characteristics cannot be predicted by instrumental measurements, but that *acceptability* cannot be predicted at a useful level.

4. Conclusions

Cultivars varied in sensory quality characteristics with consumers ranking 'Coville' and 'Hannah's Choice' above and 'Coastal', 'Elliott', 'Montgomery' and 'Weymouth' below other cultivars.

Flavor quality characteristics best predicted overall eating quality of blueberries. Various textural and visual quality characteristics also influenced consumer assessment of overall eating quality of blueberries.

No instrumental measurement adequately predicted acceptability scores.

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